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The Abdominal Musculature and Cycling Performance

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THE ABDOMINAL MUSCULATURE AND CYCLING PERFORMANCE

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by

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Thesis of

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Submitted in partial fulfillment of the requirements for the degree of Master of Science in The School of Health Sciences and Human Performance at Ithaca College has been approved.

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ABSTRACT

Purpose: The purpose was to determine if abdominal power and endurance were related to anaerobic and aerobic cycling performance and if abdominal fatigue influences cycling parameters. **Methods:** Twenty-three college aged subjects, whose $\bar{X} \pm SD$ for age, height, and weight, were 19.17 ± 1.0 years, 170.4 ± 7.5 cm, and 74.5 ± 14.1 kg, completed the front abdominal power throw and ACSM Crunch test so we could evaluate their abdominal power and endurance, respectively. The tests were completed twice across 48 hours to attenuate any learning effects. Twelve of the subjects completed the Wingate anaerobic power test on a Monark 834 E ergometer set at 7.5% of body mass. The remaining 11 subjects completed a 3.2 km cycling time trial (TT) on an Expresso S3U virtual reality bike; mean TT power and time were recorded as indicators of aerobic cycling performance. Subjects completed familiarization, baseline, and performance trials for the cycling measures; immediately before the performance trials, subjects completed abdominal crunches to fatigue. All tests were preceded and followed by a warm-up and cool-down. Dependent *t*-tests were used to assess differences between baseline and performance cycling trials, while correlational analyses were used to evaluate the relationships between abdominal and cycling measures; *p* was set at 0.05. **Results:** Abdominal muscle fatigue significantly decreased mean anaerobic power by 16% (p = 0.000) and increased the rate of fatigue by 19.8% (p = 0.004). Peak power decreased by 5.6%; the change approached significance (p = 0.088). Abdominal muscle fatigue didn't affect TT performance; however, after fatigue, abdominal power was significantly correlated with TT mean power and time (r = -0.708 and 0.704, respectively). No other significant correlations were found between abdominal and cycling measures before or after fatigue. **Conclusion:** The data showed that abdominal fatigue negatively affects anaerobic cycling performance in non-cyclist trained subjects. Consequently, individuals may wish to avoid fatiguing abdominal exercise prior to anaerobic power tests or competitions that include anaerobic power elements.

DEDICATION

This thesis is dedicated to all of the people who provided me endless support throughout this project, as well as during my entire educational career.

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Chapter 1

INTRODUCTION

Despite the increasing understanding of human physiology, the influence of abdominal strength and endurance on sport performance is unresolved. The literature on athletic performance suggests connections between the abdominal musculature and sport specific movements, but the data are inconclusive (Abt et al., 2007; Behm et al., 2009[a]; Behm et al., 2009[b]; Cowley & Swensen, 2008; Hibbs et al., 2008; Myer et al., 2006; Nesser et al., 2008; Nesser & Lee, 2009; Nikolenko et al., 2011; Reed et al., 2012; Sato & Mokha, 2009; Scibek, 1999; Stanton, Reburn, & Humphries, 2004; Tse, McManus, & Masters, 2005; Willardson, 2007). Irrespective of the inconclusive data, fitness professionals prescribe significant quantities of abdominal exercises to improve abdominal muscle function and hopefully enhance sport performance (Behm et al., 2009[a]; Behm et al., 2009[b]; Hibbs, et al., 2008; Kahle & Gribble, 2009; Nikolenko, et al., 2011; Reed et al., 2012; Tong, Wu, & Nie, 2014; Willardson, 2007).

Whereas many studies have examined the impact of core training on sport performance, only the study by Abt et al., 2007 focused on cycling; they found that abdominal fatigue altered cycling kinematics but not performance as measured by a maximum graded exercise test. Given that the abdominal musculature stabilizes the body, thereby enabling the extremities to produce force, especially the lower extremities, abdominal strength and endurance should impact cycling performance, a sport that relies heavily on the muscles of the lower body, such as the gluteals, quadriceps, hamstrings, and calf muscles, to generate power (Abt et al., 2007; Burke, 2002). To date, no study has examined the relationship of abdominal muscular power or endurance on cycling sprint and time trial (TT) performance. Further, no study has examined the effect of abdominal fatigue on cycling sprint and TT performance.

Purposes

The purposes of this study were to explore the relationships among various measures of abdominal muscle function and cycling performance and to examine the effects of abdominal fatigue on cycling sprint and TT performance.

Hypotheses

It was hypothesized that the participants who did better on the FAPT and ACSM tests would perform better on the sprint and TT tests and that abdominal muscle fatigue would reduce cycling performance.

Definition of Terms

1. ACSM Abdominal Endurance Score: The amount of successful repetitions completed during the ACSM Crunch, reported as a final score.
2. Cycling Mean Power (MP): The average amount of power in Watts produced throughout the two cycling tests.
3. Cycling Peak Power (PP): The maximal amount of power in Watts achieved throughout the two cycling tests.
4. Cycling Rate of Fatigue (RoF): The change (%Δ) of peak power decline from the beginning to the end of the Wingate cycling session.
5. Aerobic Cycling Endurance: The time taken to complete the 3.2 km TT test on the "Campus Loop", expressed in seconds (s).

Delimitations

The delimitations of this study are as follows:

1. College-aged male and female students will be used as subjects.
2. The Wingate and TT tests are accurate measures of anaerobic and aerobic power, respectively.
3. The FAPT and ACSM Crunch are accurate measures of abdominal power and endurance, respectively.
4. The abdominal fatiguing protocol is sufficient in fatiguing the abdominal musculature.

Limitations

The limitations of this study are as follows:

1. The results may only be generalized to the college-aged population.
2. The measurement variables may only indicate performance ability of the specific tests used and may not necessarily indicate cycling ability.
3. The participants' motivation and effort may vary from test to test.
4. Athletic ability and fitness level of participants may affect performance.

Chapter 2

REVIEW OF LITERATURE

Introduction

The importance of the abdominal musculature to sport performance is widely accepted despite inconsistency in the literature (Abt et al., 2007; Behm et al., 2009[a]; Behm et al., 2009[b]; Cowley & Swensen, 2008; Hibbs et al., 2008; Myer et al., 2006; Nesser et al., 2008; Nesser & Lee, 2009; Nikolenko et al., 2011; Reed et al., 2012; Sato & Mokha, 2009; Scibek, 1999; Stanton, Reburn, & Humphries, 2004; Tse, McManus, & Masters, 2005; Willardson, 2007). While many studies have examined the impact of core training on sport performance only one study used cycling as the dependent variable (Abt et al., 2007).

The abdominal musculature is important to bodily movement in general, as it provides stability while maintaining balance, enabling the extremities to produce force, especially the lower extremities (Abt et al., 2007). While many researchers have studied the physiological effects of cycling sprint and TT efforts, most focused primarily on the muscles of the lower body, such as the gluteals, quadriceps, hamstrings and calf muscles, as they are the muscles predominately used while cycling (Burke, 2002). While the muscles of the lower body are critical to the success of a cyclist, they are not the only muscles involved in cycling (Abt et al., 2007). To date, no study has examined the relationships of abdominal muscular power or endurance, and the effect of abdominal fatigue, on cycling sprint and TT performance. Therefore, the purposes of this study were to explore the relationship between abdominal power and endurance as well as the effects of abdominal fatigue, on cycling sprint and TT performance.

Cycling Performance

To assess a cyclist's performance, specific tests are used to evaluate his or her ability. These tests are conducted in either the field or lab. In most cases the tests are performed in the lab on a cycle ergometer, which can be used effectively to measure both aerobic and anaerobic performance (Inbar, Bar-Or, & Skinner, 1996; Paton & Hopkins, 2001). These tests, for example, can be used to assess an individual's performance on a variable of interest, such as cardiorespiratory capacity, muscular endurance, or muscular efficiency.

Two important components of cycling performance are frequently assessed. The first is a measure of anaerobic power. One of the most common ways to assess anaerobic power is with the Wingate Anaerobic Cycle (Wingate) test on a cycle ergometer; the test consists of a 30-second maximal sprint bout against a determined resistance based on the participant's body mass ($0.075 \text{kp} \cdot \text{kgBW}^{-1}$) (Maud & Shultz, 1989). The most common physiological measures associated with the Wingate are measurements of: 1) peak power (the highest mechanical power recorded in the first five seconds), 2) mean power (the average power sustained throughout the exercise bout), and 3) rate of fatigue as determined by the percentage of peak power decline throughout the test (Maud & Shultz, 1989). This test accurately measures anaerobic measures in trained cyclists and amateurs alike (Maud & Shultz, 1989).

The second frequently assessed component of cycling performance is aerobic power. There are multiple ways to assess aerobic power but one of the most common is by using a time trial (TT) test (Paton & Hopkins, 2001). This test assesses a participant's aerobic power by requiring her to complete a predetermined distance as fast as possible.

When assessing an individual's TT performance, stationary ergometers are often used. In general, TT tests on ergometers are better at producing reliable results because of their ability to consistently reproduce the demands of competitive events (Paton & Hopkins, 2001; Hopkins, Schabort, & Hawley, 2001). Both a Wingate and TT test will be used in this study to examine the relationships between abdominal power or endurance to cycling performance and to determine if abdominal fatigue affects these common measures of cycling ability.

Anaerobic Cycling Power and Performance

In many studies, the use of physiological measures such as oxygen debt and post-exercise blood and muscle lactate levels are garnered to assess anaerobic function (Maud & Shultz, 1989). While these parameters effectively assess anaerobic power, they are invasive procedures and require sophisticated equipment. On the other hand, performance testing using a cycle ergometer is a non-invasive, simple, and inexpensive method of collecting data. Although performance testing on a cycle ergometer supplies little physiological data, it is assumed that the performance measures of the subject reflect their actual anaerobic ability (Åstrand, 1984). Having both invasive and non-invasive options available is a luxury, but it is much easier to administer and more cost effective to conduct non-invasive performance testing.

The most commonly used non-invasive test of anaerobic power is the Wingate. One reason it is used widely is that it is reliable. Reliability means that the test can be reproduced with similar results across time. One way to assess reliability is to examine the correlation coefficient between tests. According to the developers of the Wingate, the correlation coefficients for tests performed under standardized environmental conditions range between 0.89 and 0.99, but are usually higher than 0.94 (Inbar, Bar-Or, & Skinner, 1996). In a study in which multiple trials of the arm cranking Wingate were conducted over many days by 58 children and adolescents with cerebral palsy, muscular dystrophy, and muscular atrophy, the test-retest reliability coefficients were 0.94 for peak power and 0.98 for mean power with the arm ergometer (Tirosh, Rosenbaum, & Bar-Or, 1990). Thirty-eight of these subjects also performed the cycle Wingate; the correlation coefficients of both the mean power and peak power of these 38 subjects were each 0.96, an extremely high indicator of reliability. In another study, 19 patients, 54 to 84 years of age, with chronic obstructive lung disease, completed an abbreviated cycle Wingate (15 seconds) with only 60 minutes separating the two trials (Bar-Or, Berman, & Salsberg, 1992). The correlation coefficients for both mean power and peak power were 0.89. Another study extended the findings of Bar-Or et al. (1992) and showed that a subject needs only 20 minutes between tests to produce consistent, reliable results (Hebestreit, Mimura, & Bar-Or, 1993). All the aforementioned data reveal that the Wingate is a reliable form of anaerobic power testing whether it is performed on the same day or weeks apart.

In addition to being a reliable test, the Wingate has strong validity. Validity is defined as how well a test measures what it is intended to measure. To be sure that a test is valid, it is essential to compare the test to an accepted “gold standard” method of testing. In other words, the Wingate should be compared to an anaerobic power test that is known to already be valid. This method presents a bit of a problem when evaluating the Wingate because no one test exists as a “gold standard” comparison to both peak mechanical power and mean power (Inbar, Bar-Or, & Skinner, 1996). Instead, this test is compared to certain indicators of anaerobic power performance that reflect anaerobic power capacity (peak power, mean power, and rate of fatigue). The following paragraphs describe studies analyzing such indicators of performance. A summary of studies in which the Wingate anaerobic power performance indicators are correlated with performance in sprinting, short distance swimming, a short-term ice skating task, and the vertical jump can be found in Appendix A (Inbar, Bar-Or, & Skinner, 1996).

Each of the studies listed in Appendix A are considered field tests and had subjects exert themselves maximally for short periods of time (the longest test was a 300m sprint that lasted 50-70 seconds); hence these tests are anaerobic power tasks (Inbar, Bar-Or, & Skinner, 1996). Each of these tasks requires a particular skill set, which can skew data based on the level of mastery needed for that skill. For example, when evaluating the anaerobic measures during the Sargeant Anaerobic Skate test (SAS40) ice skating shuttle, an individual who is more experienced at ice-skating will produce better anaerobic power scores in a high exertion skating task than a less experienced skater, even if the less experienced skater is considered more "anaerobically fit" in all other aspects. Consequently, some of these field tests are sport specific.

In all, the field tests are strongly correlated to Wingate tests ($r \geq 0.75$) (Inbar, Bar-Or, & Skinner, 1996). The strongest associations between the Wingate and a single field test are with the short sprint and 25-meter swim ($r = 0.92$). The weakest association was between the Wingate and the SAS40 ice skating shuttle task ($r = 0.32$). As the SAS40 ice skating shuttle performance requires a high level of skill, it is not unusual to see that this task produces a less reliable association.

If the Wingate is a true measure of anaerobic power, it follows that anaerobically trained athletes would score better than aerobically trained athletes. In a study comparing Wingate performances of differently trained athletes, including two “anaerobically trained” groups of power lifters and gymnasts, two “aerobically trained” groups of 10-km runners and ultramarathoners, and one mixed trained group of wrestlers, it was found that peak power performance in power lifters was significantly higher than in ultramarathoners (Skinner & O’Connor, 1987). The anaerobically trained athletes had much higher peak power outputs and quickly declined in performance, consequently resulting in high rate of fatigue (RoF) measures. In contrast, the aerobically trained athletes started at a much lower peak power but had a significantly lower RoF (Skinner & O’Connor, 1987). Intriguingly, all groups produced a similar mean power throughout the test. This can be attributed to the relatively high peak power (PP) measures in the anaerobically trained athletes and relatively low PP measures in the aerobically trained athletes (Skinner & O’Connor, 1987). Table 1 provides more detailed information regarding peak power, mean power, and fatigue index of this study (Skinner & O’Connor, 1987). Correlation coefficients between power indicators from Wingate tests and other power tests are shown in Appendix B.

The authors of the aforementioned study suggested that muscle fiber type might have influenced their findings. Fast twitch (FT) muscle fibers are found at a higher ratio in individuals who typically produce more anaerobic power, such as track sprinters, whereas slow twitch (ST) muscle fibers are found at a higher ratio in individuals who train for events requiring a much lower mechanical power effort, such as marathon or cross country runners (Beachle, & Earle, 2008). Fast twitch muscle fibers also fatigue

Table 1
Comparison of Measures Obtained During the Wingate Anaerobic Test on Five Groups of Highly Trained Athletes. Mean (± Standard Deviation).

Group	Peak Power (W x kg)	Mean Power (W x kg)	Fatigue Index (%)
Power Lifters	12.6(1.0)	9.3(1.3)	45.0(8.5)
Gymnasts	12.3(0.7)	9.1(0.7)	47.0(3.5)
Wrestlers	12.0(0.9)	9.3(0.9)	43.0(5.2)
10-km runners	11.9(0.6)[a]	9.3(0.8)	33.0(7.2)[a,b]
Ultramarathoners	11.2(1.1)[a]	8.8(0.6)	26.0(8.7)[a,b]

Note: [a] = Significantly different from power lifters ($p < 0.05$), [b] = Significantly different from gymnasts and wrestlers. (Skinner and O'Connor, 1987).

much sooner than ST muscle fibers (Burke, Levine, & Zajac, 1971; Thorstensson & Karlsson, 1976).

The influence of fiber type on the Wingate test was first tested using 19 male Israeli physical education students, sprinters, and long distance runners by Bar-Or et al. (1980), who found that peak power, mean power, and rate of fatigue all correlated significantly (r = 0.60, 0.63, and 0.76) with the percent of FT muscle fiber area. Similar correlations between percent FT muscle fiber type and successful performance on the Wingate test were also found in a study involving 29 Swedish participants who ranged from sedentary to competitive runners (Inbar, Kaiser, & Tesch, 1981). Therefore, researchers concluded that those who are more anaerobically fit and possess a greater ratio of FT to ST muscle fibers perform better on the Wingate. From all the data in this section of the review, it is clear that the Wingate test is a reliable and valid means with which to assess anaerobic performance.

Aerobic Cycling Endurance and Performance

As previously discussed, anaerobic power testing is an essential tool with which to assess a cyclist's ability to generate anaerobic power. Similarly, for most cyclists it is also important to assess their ability to produce aerobic power, such as by measuring their maximal oxygen consumption or VO_2 max (Barlow et al., 1985). Another common test of aerobic power is a time trial (TT), which requires the participant to complete a predetermined distance as fast as possible. Indeed, TTs are well-correlated to other markers of aerobic ability, such as VO_2 max and lactate threshold. In one study, 30 professional cyclists completed a 15 km TT on a cycle ergometer; the TT was strongly correlated ($r = 0.93$) to VO_2 max and lactate threshold (Storen et al., 2013). More importantly, TTs better simulate and correlate to actual performances than VO_2 max tests (Currell & Jeukendrup, 2008).

Some argue that a close-ended TT test, like a 15 km TT, is not the best indicator of endurance capability. Instead, a test to volitional exhaustion may provide a more valuable measure of aerobic endurance. One important characteristic to look at when choosing a test is its reliability, which can be assessed by examining the coefficient of variation (CV) between trials. The CV represents the ratio of the standard deviation and the mean, and is useful when comparing the degree of variation from one data series to another, even if the means are different from each other (Currell & Jeukendrup, 2008). The lower the CV, the more reliable the test. Research shows that volitional exhaustion protocols have a CV of <10%, whereas a closed ended test, such as a TT, is more reliable as it has a CV of <5% (Currell & Jeukendrup, 2008). Therefore, laboratory based TTs produce more reliable results than the open ended tests to exhaustion. Further, laboratory based TTs produce more reliable results compared to the same tests performed on traditional cycles in the field, where an individual must combat the elements of nature therefore lowering test-retest reliability (Paton & Hopkins, 2001). Thus, cycle ergometry TT testing in a laboratory is more suitable for collecting data than traditional TT cycle testing in the field.

Like the Wingate test, a lab based TT is also a valid measure. As stated, a valid protocol is one that resembles the performance that is being simulated as closely as possible. In one study, for example, seven competitive male cyclists competed two 40 km TT tests: one outdoors on a road bicycle and one in the lab on an ergometer. The correlation between the two tests was 0.98 (Palmer, Dennis, & Noakes, 1996). These data show that lab and road tests produce similar results. Additional support for the validity of a lab based TT is seen in Appendix C, which shows various statistics for lab based performance tests. The table indicates that the largest likelihood ratio at 95% confidence (95% LR) or the weakest ability to simulate a test's true value with 95% confidence was 7.5, meaning that, at the worst, that particular test produces about 92.5% of the experience of a traditional race or test performed on an actual bicycle. The highest 95% LR (strongest ability to simulate a test's true value with 95% confidence) was 0.6, meaning that, at worst, that particular test produces 99.4% of the experience of a traditional cycling event. Collectively, all the data in this section of the review show that lab based TTs are a valid and reliable way to assess aerobic performance.

Abdominal Musculature

The abdominal musculature is one of the most important aspects of the human body because it acts in the body's center of gravity and is from where most bodily movements stem (Gracovetsky & Farfan, 1986; Gracovetzky, Farfan, & Hueller, 1985; Panjabi, 1992; Panjabi, Tech & White, 1980). Properly functioning core musculature allows for efficient movements during acceleration and deceleration; it also stabilizes the body. As such, properly functioning core muscles are thought to prevent injuries (Behm et al., 2011; Behm et al., 2009[a]; Behm et al., 2009[b]; Clark, Lucett & Corn, 2008; Cowley & Swensen, 2008; Gracovetsky & Farfan, 1986; Gracovetzky, Farfan, & Hueller, 1985; Hodges & Richardson, 1995; Hodges & Richardson, 1996; Hodges & Richardson, 1997; Kahle & Gribble, 2009; Panjabi, 1992; Panjabi, Tech, & White, 1980; Sahrmann, 1992). Indeed, a body with weak abdominal musculature may compensate during activity by using alternative muscles groups, leading to inefficient bodily functioning, putting the individual at a higher risk for injury (Hodges & Richardson, 1995, 1996, 1997; Jesse, 1977; Nachemson, 1966).

In order for the body to work efficiently, the abdominal musculature must be developed to an optimum level so that the body can appropriately distribute weight, absorb force, and transfer ground-reaction forces (Clark, Lucett, & Corn, 2008). Weak abdominal muscles, along with strong extremities, can lead to a more rapid onset of fatigue, and hinder athletic performance (Nesser et al., 2009; Nesser & Lee, 2009; Tse, McManus, & Masters, 2005). Improving abdominal muscle function allows the kinetic chain to function efficiently, thus providing a better opportunity for improved athletic performance, reducing the risk of injury (Clark, Lucett, & Corn, 2008; Hodges & Richardson, 1995, 1996, 1997; Jesse, 1977; Nachemson, 1966; Nesser et al., 2009; Nesser & Lee, 2009; Tse, McManus, & Masters, 2005).

Recently, some have questioned whether or not abdominal muscle training is as important to improved sport performance as previously suggested (Hibbs et al., 2008). These discrepancies exist because there is no “gold standard” method to determine abdominal performance during athletic tasks (Hibbs et al., 2008). In short, the literature is unclear as to whether or not improving abdominal muscle strength, power, stability, or endurance increases sport performance (Abt et al., 2007; Myer et al., 2006; Nesser et al., 2008; Nesser & Lee, 2009; Scibek, 1999; Stanton, Reaburn, & Humphries, 2004; Thompson, Cobb, & Blackwell, 2007; Tse, McManus, & Masters, 2005).

On one hand, one study showed that a six-week abdominal strength training intervention significantly improved 5000-meter run time in trained runners (Sato & Mokha, 2009). In contrast, a core endurance program did not improve 2000m ergometer performance in 45 rowers despite significantly enhancing various measures of core functioning (Tse, McManus, & Masters, 2005). Similarly, a six-week Swiss ball abdominal training program in collegiate swimmers improved the forward medicine ball throw and postural control measures, but did not change swim performance (Scibek, 1999). In addition, some research shows that abdominal musculature development and sport performance may only relate to sport specific movements (Behm et al., 2009[a]; Behm et al., 2009[b]; Hibbs et al., 2008; Nikolenko et al., 2011; Reed et al., 2012; Tse, McManus, & Masters, 2005; Willardson, 2007).

Abdominal Power and Performance

Currently, the relationship between abdominal function and athletic performance is not clearly established. Researchers have examined the relationship between abdominal function and sport performance, but many conclude that assessments of the abdominal musculature are not directly translated into a sport specific performance measure. Unfortunately, finding one single test to assess the entire abdominal musculature is difficult because of all the different interactions between the abdomen's lumbopelvic-hip structures and muscles during different movements (Cowley & Swensen, 2008). Some assessments of abdominal musculature are only evaluated at one specific length, whereas others require expensive, immovable equipment to perform (Cowley & Swensen, 2008). This makes it very difficult to assess the abdominal musculature as a whole. Instead, the functionality of the abdominal muscles should be evaluated using distinctive tests to assess different aspects of these muscles, such as power and endurance.

For example, in a study assessing the relationship between two dynamic abdominal power tests and measures of sport performance, the front and side abdominal power throws were evaluated against an individual's performance in a 40-yard sprint, shuttle run, vertical jump, 1-repetition maximum (1RM) back squat, and relative back squat. This study produced moderate correlations between the front abdominal power throw and 1RM back squat and relative back squat. The authors suggested that this could mean that the abdominal musculature, as measured with these specific power tests, lacks specificity or does not significantly contribute to sport performance (Nikolenko et al., 2011).

Another study evaluated abdominal power as a predictor of isokinetic trunk strength and work in young men and women. Eight young men and women performed the Front Abdominal Power Test (FAPT) in which they were required to forcefully contract their abdominals to propel a medicine ball as far as possible. Researchers found that the FAPT was an accurate predictor of trunk extension and flexion strength, and work in young women. Researchers concluded that these factors can be predicted in young women by the FAPT who do not have a history of back or lower extremity injury (Cowley et al., 2009).

The results of these studies give an ambiguous picture of the relationship between abdominal power and sport performance. It is likely that to properly assess the role of the abdominal musculature in human performance, it is necessary to evaluate sport specific muscle actions and movements (Behm et al., 2009[a]; Behm et al., 2009[b]; Hibbs et al., 2008; Reed et al., 2012; Willardson, 2007). More research is needed to establish explicit relationships between abdominal power and sport performance.

Measures of Abdominal Power

As previously stated, abdominal power refers to the amount of force that can be generated by the abdominal musculature over time. There are few methods available with which to evaluate abdominal power. One study evaluated abdominal power by adapting plyometric medicine ball exercises used to improve abdominal power to a single assessment of front abdominal power (Cowley & Swensen, 2008). This front abdominal power throw (FAPT) requires the participant to generate as much force as possible by propelling a medicine ball as far as they can using short, powerful concentric contractions of the abdominal musculature. Power tests typically refer to short, quick actions of muscular force to produce movement. The FAPT meets the criteria of an abdominal power test because it requires the abdominal musculature to generate as much force as possible to propel a medicine ball as far as possible. The creators of the FAPT explored this method in a study using 24 untrained, female participants. Participants were instructed to perform explosive abdominal contractions while using their arms as a lever to project a medicine ball as far as possible. After three successful throws were completed, the individuals' abdominal power was derived from the average distance the propelled medicine ball travelled.

The researchers were able to demonstrate very high levels of test-retest reliability for the FAPT. First the researchers used an analysis of variance (ANOVA) with repeated measures to determine if the participants experienced a learning effect. The researchers found that there was only a 3% increase in performance over trials, which was not significant. Researchers concluded the subjects did not experience a learning effect from performing the exercise multiple times. Next, the researcher's calculated the FAPT's interclass correlation coefficient (ICC) (a measure of relative reliability that examines the consistency of individual scores and represents the proportion of variance in a set of scores that is attributable to the true score variance), which is usually used to measure a test's reliability. The ICC for the FAPT was 0.95, indicating excellent test-retest reliability (Cowley & Swensen, 2008). According to this study's calculated ICC, the FAPT is a very reliable measure when assessing abdominal power.

The FAPT can be considered a valid assessment of abdominal power because it was developed and adapted from a plyometric medicine ball exercise specifically designed to improve abdominal power. Abdominal power was evaluated by a powerful, concentric contraction of the front abdominal region, which, as earlier discussed, qualifies this test as an abdominal power assessment. One may argue that there is interference from the upper body when executing the powerful throw, thereby skewing the relative power of the abdominal musculature. The researchers took care in considering this factor. To limit the amount of upper body interference, participants were instructed to keep their arms above their heads throughout the entire motion with shoulders, elbows, and wrists locked, and to release the medicine ball once their hands were directly above their knees. These important aspects restrict movement from the upper body and limit upper body influence on the power throw.

Abdominal Endurance and Performance

Another important aspect of the abdominal musculature is endurance. Abdominal endurance refers to the amount of stress the abdominal musculature is able to withstand over time. Many studies have examined the relationships between abdominal muscular stability and physiological performance measures such as balance and general body control, but few have examined the relationship between abdominal endurance and sport performance (Behm et al., 2009[a]; Behm et al., 2009[b]; Behm et al., 2011; Hibbs et al., 2005; Kahle & Gribble, 2009; McGill, 2007; Reed et al., 2012; Willardson, 2007). While abdominal endurance and abdominal stability may seem similar, they are actually very different. Abdominal stability refers to the abdominal musculature's ability to stabilize the body during movement. Abdominal endurance refers to the abdominal musculature's ability to sustain repeated contractions over a period of time. Because there is limited research on how abdominal muscular endurance effects sport performance, some inferences are drawn from the studies that examine the influence of abdominal instability training on athletic performance.

For example, one study used the Star Excursion Balance Test (SEBT) to assess the relationship of core stability training on dynamic balance testing in young adults. Subjects were divided into two groups: a group that received a six-week abdominal training exercise program and a control group who did not. Researchers found that six-weeks of training significantly improved the SEBT, whereas there was no change in the control group. The authors concluded that dynamic postural control can be improved by strengthening the abdominal musculature; they speculate this can reduce a person's susceptibility to injury or speed rehabilitation from an injury (Kahle & Gribble, 2009).

A review of the use of abdominal instability or endurance exercises to train the core (abdominal) musculature found that abdominal exercises using unstable surfaces, as opposed to stable surfaces, produced greater activation of the core muscles (Behm et al., 2009[a]). While abdominal instability exercises may help protect against spinal injuries in the average person, they may not be as beneficial to athletes. Since elite athletes represent a small portion of the population, the training methods used to enhance performance in athletes will be different from the abdominal exercises used to improve general health and function in the broader population. Therefore, general abdominal instability exercises may not be applicable to an elite athlete's training program. Such athletes likely need sport specific abdominal training programs to achieve maximal performance.

Another example of how a generalized abdominal muscle-training program may not be sport specific enough was the study performed by Abt et al., 2007, who determined the correlation between abdominal stability and cycling performance. In this study, fifteen competitive cyclists performed abdominal-fatiguing exercises and then engaged in an incremental ramp cycling protocol to exhaustion to determine changes in lower extremity joint kinematics and pedaling forces as a result of compromised abdominal stability. The data show that several kinematic variables were affected after the abdominal fatiguing exercise but, more importantly, pedal force and VO_2 max remained unchanged, confirming that there were only limited effects of abdominal fatigue on cycling to exhaustion performance (Abt et al., 2007).

In all, some research suggests that abdominal endurance and instability training improve performance while other research suggests that these exercises are not sport specific enough to significantly impact performance. Further, since most abdominal training studies use instability rather than endurance exercises, it is difficult to assess the effects of abdominal endurance training on performance without additional study.

Measures of Abdominal Endurance

Abdominal endurance can be evaluated in multiple ways, but the most respected method is the Abdominal Curl-Up (Crunch) Test developed by the American College of Sports Medicine (ACSM, 2013). This test is considered the “gold standard” method when assessing abdominal endurance. The ACSM Crunch is an appropriate evaluation of abdominal muscular endurance because muscular endurance is defined as the ability of a muscle or muscle group to sustain repeated contractions against a resistance for an extended period of time. Because the ACSM Crunch test requires the participant to complete as many crunches as possible until fatigue, this test meets the criteria of a muscular endurance endeavor.

In this exercise the participant is not allowed to receive any assistance from another individual, such as having them anchor their feet when the participant performs the crunch test. When another individual assists a participant by anchoring his or her feet, the test is no longer an accurate assessment of true abdominal endurance because it will not take into account the advantage that the participant gains. Further, anchoring participant’s feet reduces abdominal musculature load, transferring a portion to the hip flexors (Kendall et al., 2005). A crunch is used in this test instead of a sit-up because a full sit-up recruits the hip flexors to lift the trunk to a sitting position (Kendall et al., 2005).

An important element to the ACSM Crunch test is ensuring that the trunk remains flexed for the entire movement. If it is not, then the abdominal muscles can relax, compromising a researcher's ability to accurately assess abdominal endurance (Kendall et al., 2005). Therefore, when performing the ACSM crunch test, the trunk should remain flexed at all times in order to ensure an accurate abdominal endurance performance.

Abdominal muscles are most commonly activated by trunk flexion through concentric muscle contractions. Trunk flexion occurs during traditional abdominal exercises, such as abdominal crunch or sit-up exercises, as a person raises their head and shoulders off the floor from a supine position toward a sitting position. Both sit-up and crunch exercises effectively activate the rectus abdominis and internal and external obliques, but crunches should be performed instead of sit-up exercises to limit hip flexor interference and allow for optimal abdominal muscle activity (Godfrey, Kindig, & Windell, 1977; Halpern & Bleck, 1979; Juker et al., 1998; Kendall et al., 2005). During the crunch exercise, the hips remain at a constant angle, the knees are bent, and the pelvis does not rotate (Kendall et al., 2005). Doing a straight leg crunch or full sit-up, allows the pelvis to rotate, putting more effort on the hip flexors, which reduces abdominal muscle activation (Kendall et al., 2005).

The ACSM Crunch is a reliable testing procedure and one of the most widely regarded means to assess abdominal endurance (ACSM, 2013). Further, it requires minimal, inexpensive equipment and as such is the gold standard for assessing abdominal muscular endurance (ACSM, 2013). The ACSM Crunch is a reliable testing modality because it has consistently been reproduced by hundreds of individuals.

The ACSM Crunch also conforms to the requirements of validity. When evaluating a test's validity, the test is compared to a gold standard exercise. In the case of abdominal endurance tests, the ACSM crunch *is* the gold standard test of abdominal endurance. Studies show that the ACSM Crunch is valid when evaluating abdominal muscle endurance (Axler & McGill, 1997; Beim, Giraldo, & Pincivero, 1997; Guimaraes, Vaz, De Campos, & Marantes, 1991; Juker et al., 1998; Kendall et al., 2005).

In all, to most effectively assess a participant's abdominal endurance, a few conditions must be closely followed so as to limit the aid of surrounding musculature and ensure the most accurate abdominal endurance performance: 1) The feet of the participant should not be anchored and instead the participant should keep his or her feet stably resting on the ground for the duration of testing, 2) A partial abdominal sit-up (crunch) should be performed with the individual lying supine, 3) The trunk must be kept in flexion the entire duration of the exercise, and 4) A crunch that creates an angle of no greater than 30 degrees should be sustained in order to ensure that hip flexor musculature is not recruited to assist and interfere with the abdominal performance. These criteria are met by the ACSM Crunch tests, a valid and reliable way to assess abdominal endurance.

Summary

Many studies have evaluated the importance of the abdominal musculature to sport performance, but there is little research examining the relationship between the abdominal muscles and cycling performance or the effects of abdominal muscle fatigue on cycling performance. Indeed, only the study by Abt et al. (2007) examined the effects of core fatigue on cycling performance as measured by its effects on VO_2 max, concluding that there was no relationship between core functioning and endurance performance. However, as stated, VO_2 max is not the only or the best means with which to assess endurance performance. Presently, no study has examined the relationship between abdominal power and endurance to cycling sprint and TT performance; the latter measures a better means with which to assess aerobic performance. Further, no study has examined the effects of abdominal fatigue on these same measures of cycling performance. Therefore, the purposes of this study were to explore the relationships among various measures of abdominal muscle function and cycling performance and to examine the effects of abdominal fatigue on cycling sprint and TT performance.

Chapter 3

METHODS

Cycling is a sport that requires many athletic components to work congruently to elicit the most efficient and effective performance. Traditionally, cyclists have focused on training the muscles of the lower body, as they are the primary muscles used to generate force during cycling (Burke, 2002). However, research shows that they are not the only muscles involved during a cycling effort, as the abdominal muscles are also engaged (Abt et al., 2007).

The abdominal musculature and its relevance to sport performance is a topic of controversy, where some research affirms the importance of the abdominal musculature in sport while other research refutes this thought (Abt et al., 2007; Myer et al., 2006; Nesser et al., 2008; Nesser & Lee, 2009; Scibek, 1999; Stanton, Reaburn, & Humphries, 2004; Thompson, Cobb, & Blackwell, 2007; Tse, McManus, & Masters, 2005). Through all this debate, there is still one aspect of abdominal muscle use during sport that is largely unstudied: how the abdominals affect cycling performance. The purpose of this study is to evaluate the relationship between abdominal power and endurance to cycling power and endurance. An additional purpose of this study is to establish if abdominal fatigue significantly affects cycling performance. The methodology for this study was based on the work of Kendall et al. (2005), Cowley & Swensen (2008), the American College of Sports Medicine (2014), and Inbar, Bar-Or, & Skinner (1996).

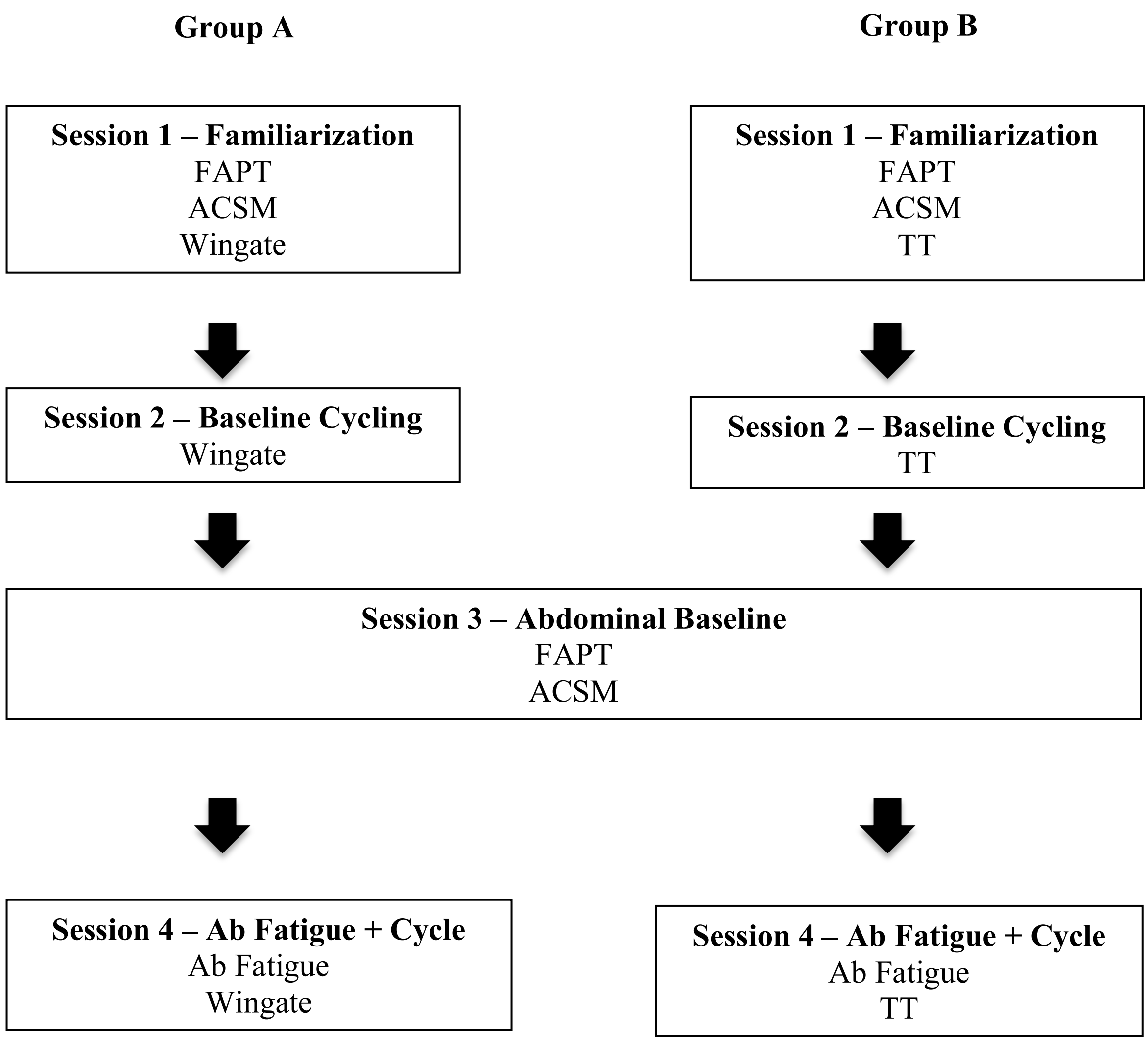
Subjects

Thirty male and female volunteers between 18 and 22 years old were recruited from the Northeastern region of the United States. Subjects were then divided into two groups based on which testing days best accommodated his or her personal schedule. Group A consisted of 12 subjects who completed the sprint (Wingate) portion of the cycling study, whereas Group B consisted of 11 subjects who completed the cycling time trial endurance (TT) portion. All subjects were required to complete the abdominal power (FAPT) and abdominal endurance (ACSM Crunch) tests, as well as the abdominal fatiguing exercise portions of this study. The subjects were not required to have any experience in sport, cycling, or exercise. Subjects were required to be fit and healthy enough to complete the requirements of this study. Subjects underwent four total testing sessions with the researcher: 1) Familiarization, 2) Cycling baseline, 3) Abdominal baseline, and 4) Abdominal fatigue plus cycling. Each session was separated by approximately 48 hr to ensure adequate recovery.

Procedures

A flowchart of testing procedures can be found in Table 2. At the first testing or familiarization session, all experimental procedures, as approved by Ithaca College's Human Subjects Research Committee, were explained. Subjects then completed a Physical Activity Readiness Questionnaire (PAR-Q) (Appendix D) to determine if they were physically healthy enough to participate. If so and they chose to participate, they then signed an informed consent (Appendix F). On this lab session and all subsequent sessions, the subjects then completed a 24 Hour Health History Form (Appendix E), which established a baseline health history; if the subject experienced any type of severe change in their daily routine, or if they had partaken in any activity that may have had an influence on the integrity of their performance, they were rescheduled or removed from the study. After the tests were explained, questions answered, and paperwork completed,

Table 2
Flow Chart of Procedures.



Note: FAPT = Front Abdominal Power Throw; ACSM = ACSM Curl-Up (Crunch) Test; Wingate = Wingate Anaerobic Cycle Test; TT = Time Trial the subject's height and weight were measured. Subjects then completed a standardized warm-up consisting of a five-minute warm-up on a Monark 834 E cycle ergometer at a pedal rate of 80 rpm with no resistance. This basic warm-up was used before all testing sessions, which were followed by a five-minute cool down that also consisted of unloaded cycling at 80 RPM. The remainder of the first lab session was to allow the subjects to practice the procedures relevant to the group they were placed in; namely, the FAPT, ACSM Crunch Test, and either the Wingate or TT test. Subjects were familiarized with all procedures so as to attenuate any learning effects and thereby improve data accuracy.

Lab session 2 was the baseline-testing day for cycling performance. Subjects in Group A performed the Wingate test, whereas Subjects in Group B performed the TT. Both groups completed the basic warm-up as described, although there was a modification for the Wingate test; namely, three "spin-ups" at the first, second, and third minutes of the warm-up were added. During these "spin-ups," the subject pedaled as fast as possible to reach a maximal rpm speed. This prepared the subjects for what to expect from the maximal pedaling bout to come. After the third "spin-up", the subject completed the remaining two minutes of the warm-up. Further, during the Wingate warm-up, a load of 1.0 kp for males and 0.5 kp for females was used (Inbar, Bar-Or & Skinner, 1996).

Lab session 3 was the baseline-testing day for abdominal power and endurance. Subjects competed the aforementioned warm-up and then completed the FAPT and ACSM Crunch with at least five minutes between each test. The abdominal power test was performed before the abdominal endurance test because the body recovers faster after shorter rather than longer efforts (Beachle & Earl, 2008).

Last, in the final testing session, subjects warmed-up as previously described, completed crunches to volitional exhaustion, and then completed their respective cycling test. Scores for this and all other sessions were recorded on specific data sheets and subsequently entered onto spreadsheets (Appendix G). All equipment was wiped down and sanitized to ensure sterile conditions for the following subject.

Measurements and Instrumentation

Prior to data collection, pilot studies were conducted to validate the experimental protocols and data collection instruments. This study required the measurement of abdominal power by way of the Front Abdominal Power Throw (FAPT) and abdominal endurance using of the ACSM Abdominal Curl-Up (Crunch) Test (ACSM Crunch). This study also required the measurement of anaerobic cycling power by evaluating peak power, mean power, and rate of fatigue during a 30 second Wingate and aerobic cycling endurance by evaluating mean power and time to complete the Campus Loop, a 3.2 km time trial track on the Expresso S3U Virtual Reality Bike. All equipment was evaluated and deemed safe for use before any subject was tested.

Front Abdominal Power Throw (FAPT)

The Front Abdominal Power Throw (FAPT) test followed all procedures and protocols constructed by its original creators (Cowley & Swensen, 2008). This test required an open area that was at least 10 meters long and 3 meters wide. An exercise mat was laid on the floor parallel (i.e., lengthwise) to the open area. The end of the mat (i.e., the end facing the open area) was placed on the floor and aligned with a piece of tape. The subject was instructed to lie on the mat in a supine position, arms along their sides, and feet shoulder width apart. The tips of the feet were aligned with the end of the mat.

The subject then bent their knees to a 90-degree angle and placed their arms over their head. In this position the shoulders were flexed, and the elbows and wrists extended with the hands supinated and thumbs from the left and right hands touching at the tips. A 2 kg medicine ball was placed in the hands of the participant, cradling the ball. The subjects were then instructed to keep the shoulders, elbows, and wrists locked in this position with the medicine ball securely cradled in the hands. The subject was instructed to perform an explosive concentric contraction of the abdominal and hip flexor muscles, while using the arms as a lever to project the medicine ball. The feet and buttocks remained in contact with the floor. The medicine ball was released from the hands when they were over the knees. The distance the medicine ball was projected from the tip of the feet to where the medicine ball landed was recorded.

Subjects were allowed several practice attempts before each trial. Each subject completed a total of three trials and an average of those scores was calculated as their FAPT score. The researcher closely monitored each trial. If the researcher deemed that any trial resulted in an action that was not allowed by the procedures (such as lifting their feet off the ground), that trial was not counted and the subject was asked to perform the trial again.

ACSM Abdominal Curl-Up (Crunch)

The ACSM Crunch test followed all procedures and protocols described in the 9th edition of *ACSM Guidelines for Exercise Testing and Prescription* (2014). Two strips of masking tape were placed on an exercise mat on the floor at a distance of 12 cm apart. The subject was instructed to lie in a supine position across the tape, knees bent at a 90-degree angle with feet flat on the floor and arms extended at their sides, such that the subjects' fingertips touched the nearest strip of tape. This was considered the bottom position. To reach the top position, subjects completed a crunch by flexing their spine to 30 degrees, reaching their hands forward until their fingertips touched the second strip of tape. A metronome was set to 40 beats per minute (bpm) to pace the subject.

At the first beep, subjects began the curl-up, reaching the top position in time for the second beep. By the third beep, subjects returned to the starting point at the bottom position and reached the top position again by the fourth beep, etc. The researcher accepted a complete repetition every time the subject successfully reached the top position and returned to the bottom position. The test concluded either when the subject reached 75 curl-ups, or when the cadence was broken due to fatigue. Each subject was instructed to give a maximal effort. The researcher demonstrated this procedure for all subjects before their respective test; subjects were allowed to practice before beginning the test.

Wingate (Group A)

Before beginning the Wingate, seat height was adjusted on the 834 E Monark cycle (Monark Exercise AB, Vansbro, Sweden) so that there was a 10 to 15-degree bend in the knee when pedaling (Inbar, Ba-Or, and Skinner, 1996); this seat height was recorded for subsequent tests. Next, the subject completed the Wingate specific warm-up as previously described. After the warm-up, the researcher loaded seven and a half percent (7.5%) of the subject's body mass in kilograms onto the ergometer's weight pan. The subject was then given a 10 second countdown, during which the subject prepared him/herself for the test by reaching a maximal pedaling speed as the researcher reached zero, whereupon the load was applied and the 30-second Wingate test began. Throughout the test, the subject pedaled as fast as they could while remaining seated on the ergometer. The researcher provided verbal encouragement and updates of how much time was left in the test. For relative measures, the subject's, mean power, peak power, and rate of fatigue were recorded. Once the test was completed, the researcher removed the load and the subject cooled down as previously described.

3.2 km Time Trial (Group B)

Before beginning the 3.2 km time trial (TT) test, the subject was introduced to the Expresso S3U Virtual Reality Bike (Interactive Fitness, Santa Clara, CA). The seat was adjusted so that there was a 10-15 degree bend in the subject's knee while pedaling. Next, the researcher explained how to use the handlebars to steer the virtual rider throughout the course, and how to use the gears to improve performance while riding up and down hills. The subject was instructed to decrease the gears when travelling up hills, and increase the gears when travelling down hills to travel faster and with greater ease throughout the course. The researcher then chose the "Campus Loop" 3.2 km course from the course selection. This is considered an easy course on the Expresso Bike with participants averaging between six to nine minutes to complete it.

Once the TT test was explained, subjects completed a five-minute warm-up on a stationary cycle at 80 rpm, and then began the test. Verbal encouragement was given throughout the test and the subject was instructed to cross the finish line completely before terminating their efforts. Upon completion of the Campus Loop 3.2 km TT, the researcher recorded the subject's mean power and peak power in Watts, and elapsed time in seconds. After the TT test, the subject performed a five-minute cool down as previously described.

Abdominal Fatiguing Exercise

The abdominal fatiguing exercise preceded the subjects' respective cycling performance on their fourth day of testing. The abdominal fatiguing exercise followed strict protocol to ensure maximal usage of the abdominal musculature. During this exercise, subjects were instructed to lie on an exercise mat in a supine position. Subjects had their arms outstretched, shoulder width apart, holding their arms straight in the air. A six-inch extension was added from the tips of the subject's fingertips. Subjects were instructed to crunch up and touch this extension. Subjects remained in abdominal flexion throughout the entirety of the test. Subjects were instructed to complete as many crunches as possible by touching their fingertips to the six-inch extension. All subjects completed crunches to exhaustion.

Criterion Measures

ACSM Abdominal Endurance Score: The amount of successful repetitions completed during the ACSM Crunch, reported as a final score.

Cycling Mean Power (MP): The average amount of power in Watts produced throughout the two cycling tests.

Cycling Peak Power (PP): The maximal amount of power in Watts achieved throughout the two cycling tests.

Cycling Rate of Fatigue (RoF): The change (%Δ) of peak power decline from the beginning to the end of the Wingate cycling session.

Aerobic Cycling Endurance: The time taken to complete the 3.2 km TT test on the "Campus Loop", expressed in seconds (s).

Height: The participant's height was measured in cm using a calibrated physician's scale.

Mass: The subject's mass was measured in kilograms using the same calibrated physicians scale in the aforementioned height subsection.

Data Analysis

Data were analyzed using IBM SPSS 22.0 software. Scores from the FAPT, ACSM Crunch, Wingate, and TT were analyzed using a correlation analysis formula to determine if there were significant relationships between abdominal power and cycling power performance, abdominal power and cycling endurance performance, abdominal endurance and cycling power performance, and abdominal endurance and cycling endurance performance. A correlation analysis was chosen because it is a statistical process for establishing relationships among variables and indicates the relationship of one variable (the independent variable) to another (the dependent variable). Statistical significance of $p < 0.05$ established a degree of confidence of the true correlation of abdominal fatigue on cycling performance.

A dependent *t*-test was used to measure if the abdominal fatigue contributed significantly to compromised cycling performance. A dependent *t*-test was chosen because it is the statistical process for establishing a significant difference for a test at one point in time to another. A statistical significance of $p < 0.05$ was used to establish a degree of confidence of a true significance between abdominal fatigue and cycling performance.

Chapter 4

RESULTS

The purposes of this study were to examine the relationship of abdominal muscular power or endurance to cycling sprint and time trial (TT) performance and to determine if abdominal fatigue effects cycling sprint and TT performance. This chapter presents descriptive statistics, correlation analyses, and *t*-test analyses organized by the dependent variables: abdominal power as measured with the Front Abdominal Power Throw (FAPT), abdominal endurance as measured by the ACSM Crunch Test (ACSM), cycling anaerobic power as measured by the Wingate test and cycling aerobic power as measured by a time trial (TT) test. Although 28 subjects were initially recruited, only 23 completed the study: two were injured outside of data collection and three chose not to complete the study. Participants were divided into two groups: Group A – Wingate anaerobic power or the sprint group; and Group B – cycling aerobic power or the TT group. Table 3 provides descriptive statistics for Group A, Group B, and all participants.

Table 3
Descriptive Statistics of Participants. Mean (± Standard Deviation).

Measure	All Participants (N = 23)	Group A (n = 12)	Group B (n = 11)
Age (yrs)	19.17(*0.98*)	19.08(*1.16*)	19.27(*0.79*)
Height (cm)	170.43(*7.62*)	167.64(*8.66*)	173.41(*4.83*)
Mass (kg)	74.47(*14.06*)	69.01(*13.55*)	80.44(*12.57*)
FAPT (cm)	155.78(*49.07*)	159.25(*44.72*)	152.00(*55.38*)
ACSM	29.65(*17.16*)	28.58(*14.26*)	30.82(*20.53*)

Note: Group A = Wingate; Group B = TT; FAPT = Front Abdominal Power Throw; ACSM = American College of Sports Medicine Abdominal Curl-Up (Crunch)

Correlation Analyses

Pearson product-moment correlations were run between abdominal musculature measures and sprint or TT performance before and after abdominal fatigue. There were no significant correlations between sprint performance and abdominal muscle power or endurance before or after abdominal muscle fatigue, as shown in Table 4. Nevertheless, the FAPT was moderately, albeit non-significantly, correlated to peak power (PP) and mean power (MP) before fatigue, as reflected by *r*-values of 0.537 and 0.441, respectively. The ACSM test and Rate of Fatigue (RoF) were also moderately, yet non-significantly, correlated (r = -0.421). In nearly all cases, fatigue reduced the relationships between abdominal and sprinting measures. After fatigue, the correlations between the FAPT and PP or MP were now weak, as reflected by non-significant *r*-values of 0.299 and 0.170, respectively. The RoF and FAPT were weakly related before and after fatigue, although the relationship did strengthen with fatigue, increasing from 0.114 to 0.257. The correlations between the ACSM test and PP or MP were weak before and after fatigue, and decreased slightly with fatigue. The correlation between RoF and the ACSM test also decreased with fatigue, moving from a moderate relationship to a weak one.

In contrast to sprinting, there were significant correlations between the abdominal and cycling TT measures. As shown in Table 4, MP and TT time were strongly and significantly related to the FAPT after abdominal fatigue, as reflected by significant *r*-values of -0.708 and 0.704, respectively. Both TT variables were moderately correlated to the FAPT before fatigue, showing that fatigue strengthened the relationships. The ACSM test and TT time and MP were weakly correlated before and after fatigue.

Table 4
Pearson Correlations of Abdominal Power and Endurance to Cycling Power and Endurance

	FAPT		ACSM	
Measure	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
Group A				
PP (W)	0.537	0.299	-0.209	-0.136
MP (W)	0.441	0.170	-0.127	-0.105
RoF (%Δ)	0.114	0.257	-0.421	-0.279
Group B				
MP (W)	-0.505	-0.708*	0.073	-0.150
Time (s)	0.525	0.704*	-0.122	0.091

Note: Group A = participants who completed the Wingate; Group B = participants who completed the TT; Pre-Fatigue = performance before abdominal fatigue; Post-Fatigue = performance after abdominal fatigue; FAPT = Front Abdominal Power Throw; ACSM = American College of Sports Medicine Partial Abdominal Curl-up (Crunch) Test; PP = Peak Power; MP = Mean Power; RoF = Rate of Fatigue; *$p < 0.05$

T-Test Analyses

Dependent *t*-tests were conducted to determine if abdominal fatigue affected sprint and TT performance. As shown in Table 5, abdominal fatigue significantly decreased anaerobic performance, as MP decreased by -16.0% ($p<0.01$) and the RoF increased by 19.8% ($p<0.01$). Additionally, PP decreased by 6.2%, a change that approached significance ($p = 0.088$). In contrast to anaerobic performance, fatigue didn't significantly affect TT or aerobic performance. In all, these findings show that abdominal fatigue significantly affected cycling anaerobic power but not endurance performance.

Table 5
Dependent t-Test Analyses Comparing Pre- and Post-Abdominal Fatigue Measures. Mean (± Standard Deviation).

	Pre-Fatigue	Post-Fatigue	%Δ	*t*
Group A				
PP (W)	643.17(*145.01*)	607.27(*143.50*)	- 6.21	0.872
MP (W)	486.75(*115.35*)	408.83(*92.91*)	-16.0	5.001**
RoF (%Δ)	42.01(*8.0*)	50.32(*7.2*)	19.8	-3.674**
Group B				
MP (W)	228.18(*33.39)*	220.09(*37.29*)	- 3.6	1.665
Time (s)	382.73(*24.30*)	388.00(*31.06*)	1.3	-1.303

Note: Group A = Wingate; Group B = TT; Pre-Fatigue = performance before abdominal fatigue; Post-Fatigue = performance after abdominal fatigue; PP = Peak Power; MP = Mean Power; RoF = Rate of Fatigue; Time = time to complete the TT; $^{**}p < 0.01$

Summary

Correlational analyses were conducted to determine if abdominal power and endurance were significantly related to cycling anaerobic and aerobic power. The only significant correlations were the strong relationships between the FAPT and TT MP (r = -0.708) and time (r = 0.704) after fatigue. All other correlations were non-significant, and ranged from moderate to weak. Fatigue decreased nearly all correlations except the RoF. These findings show that abdominal power is strongly related to TT mean power and time after abdominal muscle fatigue. Dependent *t*-test were conducted to determine if abdominal fatigue significantly altered cycling anaerobic and aerobic power. Abdominal fatigue did not affect TT performance, but it did reduce sprint performance, as MP decreased significantly by 16.0% (p<0.01), RoF increased significantly by 19.8% (p<0.01), and PP declined by 6.2%, albeit non-significantly (p = 0.088). Hence, abdominal muscle fatigue affects anaerobic but not aerobic cycling performance.

Chapter 5

DISCUSSION

The purposes of this study were to explore the relationships among various measures of abdominal muscle function and cycling performance and to examine the effects of abdominal fatigue on cycling sprint and TT performance. It was hypothesized that the participants who did better on the FAPT and ACSM test would perform better on the sprint and TT tests and that abdominal muscle fatigue would reduce cycling performance. There were no significant correlations between abdominal muscle function and cycling performance before abdominal muscle fatigue. Indeed, core function and cycling performances were only weakly to moderately correlated prior to fatigue, as reflected by r-values ranging from 0.073 to 0.537. The strongest correlations were between the FAPT and both sprint and TT performance. The FAPT, a measure of abdominal power, was moderately correlated to peak and mean anaerobic power, as reflected by r-values of 0.537 and 0.441, respectively. These data show that subjects with greater abdominal power may generate more watts during a sprint test. Similarly, TT power and time were also moderately correlated to the FAPT, as reflected by r-values of -0.505 and 0.525, respectively. The inverse or negative correlation between the FAPT and TT power suggests that as abdominal muscle power increases, TT power decreases, a stark contrast to the original hypothesis. In all, pre-fatigue, the FAPT was better related to cycling performance than the ACSM test, as four out of the five measures were moderately related to the FAPT, whereas four out of the five cycling measures were weakly related to the ACSM test. The only moderate correlation with the ACSM test was with the RoF, and this was a negative or inverse relationship, suggesting that greater abdominal muscle endurance was linked to lower RoF, which is consistent with the research hypothesis.

The relationships between abdominal muscle and cycling performance were also examined after fatigue to determine its effects on them. In nearly all situations fatigue weakened the correlations, except for the relationship between the FAPT and TT time and power, which increased from moderate to strong as reflected by increases from -0.505 to -0.708 and 0.525 to 0.704 for TT power and time respectively; the correlations also reached significance. The inverse or negative correlation between the FAPT and TT power suggests that as abdominal power increases, TT power decreases. The fact that TT power and time are related oppositely to the FAPT is not surprising. As TT power decreases, TT time will increase. Given that this is the first study to examine the relationships between certain measures of abdominal muscle function and cycling performance, my data cannot be compared to other research findings.

The second objective was to determine how abdominal fatigue affected cycling sprint and TT performance. It was found that abdominal muscle fatigue significantly decreased mean anaerobic power and increased rate of fatigue by -16.0% ($p<0.01$) and 19.8% ($p<0.01$), respectively. Fatigue also decreased peak anaerobic power by -6.2%, but this change was not significant ($p = 0.088$). In contrast, abdominal fatigue did not affect aerobic cycling, although as mentioned it strengthened the correlations between the FAPT and TT power and time. The contrasting effect of fatigue on sprint and TT performance likely reflects the nature of the tests. The sprint or Wingate test is a whole body exercise, requiring significant stabilization of the trunk to generate as much power as possible, typically 175% of peak aerobic power. The TT test, on the other hand, was completed at a much lower intensity as reflected by the difference in watts between the two tests. Although not quantified in this study, a previous study showed that a similar 3.2 km virtual TT on an Expresso Bike elicited an RPE, HR, and blood lactate of 16, 161 bpm, and 10.5 mM, respectively, in 20 subjects with similar characteristics as the subjects in this study (Zybert et al., 2014). Collectively, these data suggest that the 3.2 km TT is completed at roughly 80% of age predicted maximum heart rate, nearly 85% of VO_2 max based on the Borg RPE scale, and nearly 92% of VO_2 max based on actual gas measurements in Zybert et al. (2014). In all, the TT was completed at a much lower intensity than the sprint test; consequently, the abdominal muscles may not be as important. Perhaps a longer TT would elicit different data, as abdominal fatigue marginally decreased TT power by 3.6% over 3.2 km ($p = 0.127$).

The TT data in this study are consistent with previously reported findings, which showed that abdominal muscle fatigue does not alter cycling endurance performance as measured with a maximum graded exercise test (Abt et al., 2007). Other studies evaluating rowers and swimmers also showed no significant benefits or relationships between sport performance and abdominal muscle function (Scibek, 1999; Tse, McManus, & Masters, 2005). In contrast, the sprint data from this study are inconsistent with literature, as an abdominal muscle fatigue protocol reduced sprint performance. These data suggest that anaerobic power athletes, especially cyclists who compete in sprint events, can be affected by abdominal fatigue. Cyclists and coaches can use this information to better inform training programs. For example, coaches may discourage their athletes from doing fatiguing exercises before competition. Further, the data suggest that sprint cyclists should integrate abdominal muscle exercises into their training programs. This training wouldn't enhance performance; instead, it may attenuate reduced performance with abdominal muscle fatigue.

Indeed, core training minimally affects performance and its effects may only apply to sport specific movements (Behm et al., 2009[a]; Behm et al., 2009[b]; Hibbs et al., 2008; Nikolenko et al., 2011; Reed et al., 2012; Tse, McManus, & Masters, 2005; Willardson, 2007). Nevertheless, the literature promotes core training as a means to enhance performance despite the lack of evidence. The literature does show that core training improves core function; it does not, however, show that changes in core function improve sport performance other than the study by Sato & Mokha, 2009, who found that a 6-week core training program decreased 5 km run time in trained athletes.

Summary

The current study found no significant correlations between abdominal and cycling variables before abdominal muscle fatigue. At best, the correlations were moderate, and many were weak. Abdominal muscle fatigue reduced all correlations except those between the FAPT and TT power and TT time; these correlations improved and were significant. Interestingly, the correlation between the FAPT and TT power was negative, meaning that as FAPT increased, TT power decreased. Abdominal fatigue did not affect TT performance, but it did affect sprint cycling performance, decreasing MP by 16.0% ($p = 0.000$) and increasing RoF by -19.8% ($p = 0.004$). Additionally, abdominal muscle fatigue lowered PP by -6.2%, which approached significance ($p = 0.088$).

The most important take away from the current study is that it is the first to establish that abdominal fatigue significantly reduces cycling sprint performance, a finding that suggests cyclists should improve their abdominal muscle function so to limit the effects of abdominal fatigue on cycling sprint performance.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Many studies have examined the impact of core training on sport performance. Only one study focused on cycling; the authors found that abdominal fatigue altered cycling kinematics but not performance as measured by a maximum graded exercise test. Given that the abdominal musculature stabilizes the body, thereby enabling the extremities to produce force, especially the lower extremities, abdominal strength and endurance should impact cycling performance. To date, no study has examined the relationship of abdominal muscular power or endurance to cycling sprint and time trial (TT) performance. Further, no study has examined the effect of abdominal fatigue on cycling sprint and TT performance. Therefore, the purposes of this study were to explore the relationships among various measures of abdominal muscle function and cycling performance and to examine the effects of abdominal fatigue on cycling sprint and TT performance. To that end, 23 college-aged individuals were divided into two groups. One group completed the Wingate anaerobic power test and the other a 3.2 km TT. The results of these tests were correlated to measures of abdominal power and endurance as measured with the front abdominal power throw (FAPT) and the ACSM crunch test, respectively. The cycling tests were repeated after a bout of abdominal muscle fatiguing exercises to see if the correlations were altered and if the fatigue affected performance.

There were no significant correlations between abdominal muscle function and cycling performance before abdominal muscle fatigue. Indeed, core function and cycling performance were only weakly to moderately correlated prior to fatigue. The strongest and only significant correlations were between the FAPT and sprint and TT performance. In short, abdominal power was moderately and positively correlated to peak and mean anaerobic power as well as TT time, and moderately and inversely related to TT power. The inverse or negative correlation between the FAPT and TT power suggests that as abdominal muscle power increases, TT power decreases, a stark contrast to the original hypothesis. In all, pre-fatigue, the FAPT was better related to cycling performance than the ACSM test. Fatigue weakened the correlations, except for the relationships between the FAPT and TT time and power, which increased from moderate to strong; the correlations also became significant.

Dependent *t*-tests were run to determine how abdominal fatigue affected cycling sprint and TT performance. Abdominal muscle fatigue significantly decreased mean anaerobic power and increased rate of fatigue by -16.0% ($p<0.01$) and 19.8% ($p<0.01$), respectively). Fatigue also decreased peak anaerobic power by -6.2%, but this change was not significant ($p = 0.088$). In contrast, abdominal fatigue did not affect aerobic cycling, although as mentioned it strengthened the correlations between the FAPT and TT power and time.

Conclusions

Based upon the analysis of data collected in the current study, the following conclusions can be made in this subject cohort:

1. The abdominal measures used in this study were moderately to weakly correlated to cycling performance parameters before abdominal fatigue. None of these correlations were significant.

2. Abdominal fatigue weakened all correlations except those between abdominal power and TT power and time, which moved from moderate to strong and reached significance.
3. Abdominal power correlated better to the various cycling tests than abdominal endurance.
4. Abdominal fatigue significantly reduced cycling sprint or anaerobic performance, but did not affect TT or aerobic cycling performance.

Recommendations

Based upon the results collected in the present study, the following recommendations are made for future research:

1. Evaluate if abdominal muscle training programs will improve cycling sprint performance.
2. Use trained cyclists as subjects.
3. Use a longer TT.
4. Use different measures of core function—perhaps tests that challenge the trunk extensors rather than just the flexors as in this study.

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Appendix A

CORRELATIONS BETWEEN THE WINGATE ANAEROBIC TEST SCORES AND PERFORMANCE IN ANAEROBIC PERFORMANCE TESTING

Correlation Between the Wingate Anaerobic Test Scores and the Performance in Anaerobic Performance Testing

Wingate Index	Reference	*N* and gender	Exercise	*r*	Comments
PP	35M	40m run speed	0.84	10- to 15-year olds, random sample	Bar-Or and Inbar (1978)
PP	9M	50m run time	-0.91	Active young adults	Kaczkowski et al. (1982)
PP	24M	91.5m skate	0.83	10-year old ice hockey players	Rhodes et al. (1985)
PP	56M	50-yard run time	-0.69	10- to 15-year olds, active	Tharp et al. (1985)
PP	56M	Vertical jump	0.70	10- to 15-year olds, active	Tharp et al. (1985)
PP	87M	500m skate speed	0.66	US National team	Thompson et al. (1986)
PP	24M	SAS 40	0.32	Junior A ice hockey players	Watson and Sargeant (1986)
MP	9F&M	25m swim time	-0.90	8- to 12-year old swimmers	Inbar and Bar-Or (1977)
MP	9F&M	25m swim time	-0.92	8- to 12-year olds, WAnT arm	Inbar and Bar-Or (1977)
MP	22F&M	300m run time	-0.88	8- to 12-year old swimmers	Inbar and Bar-Or (1977)
MP	35M	300m run speed	0.85	10- to 15-year olds, random sample	Bar-Or and Inbar (1978)
MP	24M	91.5m skate	0.71	10-year old ice hockey players	Rhodes et al. (1985)
MP	56M	50-yard run time	0.69	10- to 15-year olds, active	Tharp et al. (1985)
MP	56M	Vertical jump	0.74	10- to 15-year olds, active	Tharp et al. (1985)
MP	24M	SAS 40	0.79	Junior A ice hockey players	Watson and Sargeant (1986)
MP	87M	500m skate speed	0.76	US National team	Thompson et al. (1986)
MP	10M	300m cycle time	0.75	25.7-year old cyclists	Perez et al. (1986)

Note: PP = peak power, MP = mean power, SAS40 = Sargeant Anaerobic Skating test
Inbar, Bar-Or, and Skinner 1996.

Appendix B

CORRELATIONS BETWEEN THE WINGATE ANAEROBIC TEST AND OTHER LABORATORY ANAEROBIC INDICES

Correlation Between the Wingate Anaerobic Test Scores and Other Laboratory Anaerobic Indices

WAnT index	*N*	Laboratory test or index	*r*	References
PP	15	Margaria step-running	0.79	Ayalon et al. (1974)
PP x kg	11	Margaria step-running	0.84	Jacobs (1979)
PP x kg	15	Margaria step-running	0.00	Taunton et al. (1981)
PP	19	PP-Thorstensson isokinetic	0.61	Inbar, Kaiser, and Tesch (1981)
MP	19	PP-Thorstensson isokinetic	0.78	Inbar, Kaiser, and Tesch (1981)
MP	16	Maximal O2 debt	0.86	Bar-Or et al. (1977)
PP	11	O2 debt post WAnT	0.85	Jacobs (1979)
MP	11	O2 debt post WAnT	0.63	Jacobs (1979)
MP	14	O2 debt post WAnT	0.47	Tamayo et al. (1984)
rev/30s	11	Lactate post WAnT	0.60	Jacobs (1979)
MP x kg	14	Lactate post WAnT	0.60	Tamayo et al. (1984)
PP x LBM	19	%FT area	0.60	Bar-Or et al. (1980)
% fatigue	19	FT area/ST area	0.75	Bar-Or et al. (1980)
MP x LBM	19	FT area/ST area	0.63	Bar-Or et al. (1980)
PP	29	% FT	0.72	Inbar, Kaiser, and Tesch (1981)
MP	29	% FT	0.57	Inbar, Kaiser, and Tesch (1981)
PP	9	FT area	0.84	Kaczkowski et al (1982)
MP	9	FT area	0.83	Kaczkowski et al (1982)

Note: PP = peak power, MP = mean power, LBM = lean body mass, FT = fast twitch muscle fiber, ST = slow twitch muscle fiber

Inbar, Bar-Or, and Skinner, 1996.

Appendix C

TYPICAL ERROR OF ESTIMATE OF PERFORMANCE TIME IN A COMPETETIVE CYCLING EVENT BASED ON PERFORMANCE IN A TEST

Typical error of estimate of performance time in a competitive cycling event based on performance in a test

Measure	Mean±SD	*N*	Performance Test; Ergometer	*r*	Typical Error (%)	95% LR (%)	Reference
40km time	61±3	7	Simulate 40km time; Kincycle	0.98	1.0	0.6-2.4	Palmer et al.
40km time	58±1.3	14	VO2 at ventilatory threshold; Lode	-0.82	1.3	0.9-2.1	Hoogeveen et al.
40km time	58±1.3	14	VO2 max; Lode	-0.71	1.6	1.1-2.6	Hoogeveen et al.
40km time	61.3±2.3	8	Power at ventilatory threshold; Mijnhardt KEM3	-0.81	2.2	1.4-4.8	Hopkins & McKenzie
15km time	23.5±1.5	22	VO2 at ventialtory threshold; Monark	-0.93	2.3	1.8-3.4	Miller & Manfredi
40km time	56.3±3.7	15	1h mean power; Monark	-0.88	3.1	2.3-5.0	Coyle et al.
20km time	37.3±4.2	19	Peak Power; Lode	-0.91	4.7	3.5-7.0	Hawley & Noakes
16.1km time	22.5±1.2	16	Peak power; SRM	-0.46	4.7	3.5-7.0	Balmer et al.

Note: All participants were competitive male cyclists; Studies are sorted by typical error.

Appendix D

QUESTIONNAIRE (PAR-Q)

Name: ____ Date: __________

DOB: __________________ Age: __________________

Emergency Contact: ________________________ Phone: ________________

Questions

Yes No

[ ] [ ] Has your health care provider ever said that you have a heart condition AND that you should only perform activity recommended by a doctor?

[ ] [ ] Do you feel pain in your chest while performing physical activity?

[ ] [ ] Have you experience chest pain while NOT performing physical activity in the last month?

[ ] [ ] Do you lose your balance because of dizziness or do you ever lose consciousness

[ ] [ ] Do you have a bone or joint problem that could be made worse by a change in your physical activity?

[ ] [ ] Is your doctor currently prescribing drugs for your blood pressure or heart condition?

[ ] [ ] Do you know of any other reason why you should not participate in physical activity?

By signing below, you acknowledge that you have answered all questions truthfully to the best of your knowledge and will inform the researcher of any changes in your health that may affect the way in which you answer this form.

Subject Signature: ____

Appendix E

24 HOUR HEALTH HISTORY FORM

Name: ____ Date: __________________

Present Health Status (please check all that apply)

[ ] Nausea	[ ] Sore Throat	[ ] Headache
[ ] Body Ache	[ ] Chills	[ ] Lethargy
[ ] Nasal Drip	[ ] Cramping	[ ] Muscle Aches
[ ] Chest Pain	[ ] Shortness of Breath	[ ] Dizziness

Diet	Yes	No
Have you consumed alcohol in the past 12 hours?	[ ]	[ ]
Have you used caffeine or nicotine in the last three hours?	[ ]	[ ]
Did you eat any food in the last three hours?	[ ]	[ ]
If so, explain:		

Exercise		
Have you exercised in the last 24 hours?	[ ]	[ ]
If so, explain:		
Has your exercise routine changed at all since the last exercise test?	[ ]	[ ]
If so, explain:		

Prescription Drugs		
Have you taken any over-the-counter drugs (i.e. cold meds) in the last 24 hours?	[ ]	[ ]
Have there been any changes in any of your current prescription drugs recently?	[ ]	[ ]
If so, explain:		

Injury	Yes	No
Have you experienced any sort of pain in the last 24 hours?	[ ]	[ ]

If so, explain:

Have you twisted, sprained, or broken anything since your last exercise test?[	[ ]	[ ]

If so, explain:

Is the any possible injury we should know about before performing the test?	[ ]	[ ]

If so, explain:

Sleep Pattern		
Has your sleep pattern changed since the last exercise test?	[ ]	[ ]
Do you feel drowsy, tired, or run down at this time?	[ ]	[ ]
Have there been any changes since the last exercise test that you feel could compromise your performance on today's exercise test?	[ ]	[ ]

If so, explain:

Other questions/comments/concerns, please state below:

Appendix F

INFORMED CONSENT FORM

The Relationship Between the Abdominal Musculature and Cycling Performance

1. **Purpose of the Study:** The purpose of this study is to determine if an individual's abdominal power and endurance have an effect on cycling power output or cycling endurance performance.

2. **Benefits:** You may benefit from participating in this study because you will learn your abdominal power and endurance values as well as your anaerobic power and aerobic endurance capacity and be able to see how you compare to others of your age and gender. You will also receive firsthand experience on how to execute a Frontal Abdominal Power Test, an ACSM Partial Curl-Up (crunch) Test, and a Wingate Cycle Test or Time Trial test, which may benefit your future exercise testing experience. It is hoped that the data generated from your participation in this study will provide beneficial information to the scientific community.

3. **Requirements of the Participant:** You will be required to be at least 18 years of age to participate in this study. This study will require you to provide a maximal abdominal power performance, perform partial crunches to abdominal fatigue, perform an abdominal fatiguing exercise, and provide a maximal power cycling effort or submaximal cycling time trial test. All tests will be performed in the Exercise Physiology Lab in the Center for Health Sciences (CHS) 303C. You will receive instructions before testing on how to prepare yourself. Upon arriving to the testing facility, you will be asked to complete a Physical Activity Readiness Questionnaire (PAR-Q) as well as a 24-hour health history questionnaire. It is possible that you may be excluded from the study if possible health risks are found in these questionnaires. This study includes three parts: you will be instructed to participate in an abdominal power, abdominal endurance, and cycling power or cycling endurance efforts. During the abdominal performance portion of this study, you will be instructed to complete the Frontal Abdominal Power Throw (FAPT), a test of powerful abdominal contractions to assess abdominal power, and the ACSM Abdominal Curl-Up (ACSM Crunch) test, an assessment of abdominal endurance. During the cycling performance portion of this test, you will be instructed to complete either the Wingate Cycle Test (Wingate), a test of maximal anaerobic power, or a 3.2 km time trial (TT) test on a virtual reality cycle to assess cycling endurance. It is crucial that you give a maximal effort during each of these tests. When engaging in the FAPT, you will be asked to use maximal abdominal power to propel a 2kg medicine ball as far as possible. During the ACSM Crunch, you will be completing a crunch to the rhythm of a cadence set at 40 beats per minute. You are asked to complete as many crunches as possible until fatigue/failure. The Wingate test requires you to pedal as fast as possible for 30 seconds on a cycle ergometer against 7.5% of your body mass in kilograms. The TT test requires you to complete a 3.2 km track as fast as possible on a virtual reality bike. The estimated total participation time for each participant is 90 minutes.

Initials _____________

4. **Risks of Participation:** The risk of injury or death involved with this study is minimal. Some risks of this study include, but are not limited to, muscle soreness, skeletal muscle injury, and cardiac events resulting in death. The chance of a cardiac event occurring during exercise in your age group is low. To minimize the risk of injury, you will warm-up and cool down prior to and after each test and training session. If you do not feel well during the test, you may terminate the session at any time. The researcher will be able to provide standard first aid care in the event that you are injured.

   If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost for such care will be charged to you. If you have insurance, you may bill your insurance company. You will be responsible to pay all costs not covered by your insurance. Ithaca College will not pay for any care, lost wages, or provide any other financial compensation.

5. **Withdrawal From the Study:** Participation in this study is voluntary and you may withdraw at any time if you choose. You will not be penalized in any way and your information will be kept confidential.

6. **Use of Records/Confidentiality:** Information gathered during this study will be kept in complete confidence. Only the researcher, researcher assistants, and thesis advisor will be allowed to access this information, which will be kept in a drawer Dr. Tom Swensen's office (CHS 313) under lock and key. At the completion of testing, your information will be kept for five years for research purposes only and will be destroyed once the five year period has concluded. To further ensure confidentiality, all files will be number coded and data collection instruments will be kept separately from Informed Consent Forms and sign-up sheets. Only the researcher, researcher assistant, and the thesis advisor will know the coding system.

7. **Freedom of Consent:** I have read and understand the above document. I agree to participate in this study and realize that I may withdraw at any time. I also understand that should I have any questions regarding the study that I should contact the researcher. I also verify that I am at least 18 years of age.

______________________________ ______________________________________

Participant Name (Please Print) Signature Date

______________________________ ______________________________________

Researcher Name Signature Date

Appendix G

SUBJECT DATA SHEET

(Side 1)

Group: _________

Name: ____________________________ Date: __________ Sex: _______

DOB: ____________Age: ________Height: ________ Weight: ________

Resting HR: __________

Testing Day #1: Familiarization

FAPT

Trial 1: _____________

Trial 2: _____________

Trial 3: _____________ Mean Power: ________

ACSM Crunch

Score: _____________

Wingate

Resting HR: _______________

Load: ____________________

Seat Height: _______________

Mean Power: ______________

Peak Power: _______________

Rate of Fatigue: ____________

Mean HR: 1_____2_____3_____=______

TT

Seat Height: _______________

Resting HR: _______________

Mean HR: ________________

Peak HR: _________________

Mean Power: ______________

Peak Power: ______________

Time (s): _________________

Appendix G, continued

SUBJECT DATA SHEET
(Side 2)

Group: ________

Name: ______________________________Date: __________ Sex: _______

DOB: ____________Age: ________ Height: ________ Weight: ________

Testing Day #2: Abdominal Base Scores

FAPT

Trial 1: _____________

Trial 2: _____________

Trial 3: _____________

Mean Power: ________

ACSM Crunch

Score: _____________

Appendix G, continued

SUBJECT DATA SHEET

(Side 3)

Group: ________

Name: ______________________________Date: __________ Sex: _______

DOB: ____________Age: ________Height: ________ Weight: ________

Resting HR: __________

<u>Testing Day #3: Cycling Base Scores</u>

Wingate	**TT**
Resting HR: _______________	Seat Height: _______________
Load: ____________________	Resting HR: _______________
Seat Height: _______________	Mean HR: ________________
Mean Power: ______________	Peak HR: _________________
Peak Power: _______________	Mean Power: ______________
Rate of Fatigue: ____________	Peak Power: ______________

Mean HR: 1_____2_____3_____=______ Time (s): _________________

Appendix G, continued

SUBJECT DATA SHEET
(Side 4)

Group: ________

Name: ______________________________Date: __________ Sex: _______

DOB: ____________Age: ________Height: ________ Weight: ________

Resting HR: ___________

Testing Day #4: Abdominal Fatigue and Wingate or TT

Abdominal Fatigue Score: ______________

Wingate

Resting HR: _______________

Load: ____________________

Seat Height: _______________

Mean Power: ______________

Peak Power: _______________

Rate of Fatigue: ____________

Mean HR: 1_____2_____3_____=______

TT

Seat Height: _______________

Resting HR: _______________

Mean HR: ________________

Peak HR: _________________

Mean Power: ______________

Peak Power: ______________

Time (s): _________________